

of some of these materials may also be used as the electroactive polymer in transducers.

[0051] Electronic drivers, such as the drivers 112 and 118, are typically connected to the electrodes of an electroactive polymer transducer. The voltage applied to an electroactive polymer will depend upon specifics of an application. For example a transducer may be driven electrically by modulating an applied voltage about a DC bias voltage. Modulation about a bias voltage improves sensitivity and linearity of the transducer to the applied voltage.

[0052] The deflection of an electroactive polymer can be used in a variety of ways to produce mechanical energy. Generally speaking, electroactive polymer actuators include extenders, bending beams, stacks, and diaphragms. In the binding 152 of the adjustable brace, the linear extension or contraction of the electroactive polymer in response to voltage from a driver is used to increase or decrease the tension in binding. The controller 98 can vary the tension in a binding of one or more of the attaching elements to respond to changing tension in the binding due to muscle contraction and expansion, muscle density, limb position, or another treatment variable captured in a program instruction that is executed by the microcontroller 100.

[0053] An electroactive polymer can also be used as a sensing transducer for the binding 152 of the brace attaching element 150. As the electroactive polymer 202 of a transducer is deflected the voltage at the electrodes 204 and 206 changes. The electroactive polymer sensing transducer element 174 is attached to the fabric of the binding 152 so that the transducing element is stretched or compressed by the changing tension in the binding. The voltage at the electrodes of the transducer element 174 can be used to signal a binding tension brace parameter to the controller 98.

[0054] The adjustable brace 80 includes provisions for bending the bracing element 84 in a direction generally orthogonal to the limb to adjust the fit of the bracing element to a user's limb and to alter the compartmental loading of the braced joint. Referring to FIG. 6, the upper 86 and lower 88 levers of the bracing element 84 are connected by a hinge pin 136 facilitating relative rotation of the levers about the pin. A disk 256 attached to the hinge pin 136 on the limb side of the bracing element 84 protects the limb from the moving components of the bracing element and may be used to compress a condyle pad 257 providing lateral stability to the joint. The hinge pin 136 passes through a central aperture in a loading transducer 258 retaining the transducer in rotational engagement with the proximal end to the upper lever 86. A loading disk 261 with an offset central portion abuts an end of the loading transducer 258 and is restrained to the upper 86 and lower 88 levers by sliding blocks 264 and 265 welded to the levers and engaging the loading disk. When the length of the transducer 258 changes, the distal ends of the upper 86 and lower 88 levers are deflected in the direction of the axis of the hinge pin 136 or substantially normal to the limb. The upper 86 and lower 88 levers may include transverse hinges 260 to reduce the force necessary to deflect the levers. The loading transducer 258 illustrated in FIG. 6 is a piezoelectric or electro-active polymer transducer having a length that is variable in response to a voltage applied by a driver 116 that is controlled by the controller 98. The lateral profile of the bracing element can be varied to conform to the user's limb and alter the compartmental

loading of the joint. In addition, the brace 80 includes one or more sensing transducers 138, such as a strain gauge to sense the stress in, and result from, the displacement of a lever of the bracing element 84. The sensing transducer 138 provides an input signal and feedback to the controller 98 related to the displacement of the levers 86 and 88 by the loading transducer or as a result of external loading. If a prescribed level of displacement or stress is sensed indicating a lateral blow to the limb, the controller 98 can cause the loading transducer 258 to deflect the bracing element to aid in resisting displacement of the brace that might injure the joint.

[0055] A shaft encoder 127 is also attached to the hinge pin to sense changes in the relative angular positions of the upper 86 and lower 88 levers. The controller 98 can vary the force exerted by the attaching elements, the lateral deflection of the brace, or the assistance or resistance of the brace to joint flexing as a function of the angular position of the levers and, therefore, the limb elements. For example, the force exerted by the tensioning structures might be reduced when the foot is raised and the tibia is not in position to apply an injurious load to the joint.

[0056] The adjustable brace 80 also includes a loading transducer to vary the force required for relative rotation of the upper 86 and lower 84 levers about the hinge 136. As illustrated in FIG. 3, an electroactive polymer filament 140 is used to assist joint extension or resist flexion in a first direction. A second electroactive polymer filament 141 reeved on the opposite side of the bracing element joint can apply extension and flexion forces opposing those of the first filament 140. The electroactive polymer filament 140 is anchored to the upper 86 and lower 88 levers and passes over a leveraging sheave 142 at the hinge 136. Voltage applied to electrodes of the electroactive polymer filament 140 by the driver 114 in response to signals from the controller 98 causes the length of the filament to change assisting extension or resisting flexion of the joint as desired for a specific treatment regimen. The loading transducer 140 may also be used to assist flexion and resist extension by routing the filament on the opposite side of the sheave 142.

[0057] Referring to FIG. 7, a linear actuator 300 can also be used to in assisting or resisting joint flexing. A piston rod 302 of the linear actuator 300, attached to the upper lever 86, is attached to the lower lever 88 of the bracing element 84 by a filament 304. The filament 304 passes over a sheave 142 at the hinge 136 and an idler 306 that reduces side loading of the piston rod 302. The linear actuator 300 may be a pneumatic or hydraulic actuator having a valve 308 with flow characteristics controllable by the controller 98. By controlling the flow into and out of the linear actuator 300 the force required to displace the piston rod 302 can be varied. The controller 98 can vary the force exerted by the actuator 300 as a function of the angular position of the levers 86 and 88 as sensed by the shaft encoder 127. If a source of pressurized fluid is provided, the actuator 300 can serve as a motor generating a force assisting extension of the joint (or assisting joint flexion by reversing the position of the filament 304 on the sheave 142).

[0058] An alternative linear loading transducer 300 incorporating a magneto-rheological fluid can be utilized to provide variable resistance under the control of the controller 98. FIG. 9 illustrates a linear loading transducer com-